DIVISION OF GEOLOGICAL & GEOPHYSICAL SURVEY

STATE OF ALASKA
DEPARTMENT OF NATURAL RESOURCES

GEOLOGY AND GEOLOGIC HAZARDS OF THE EASTERN COAST OF THE KENAI PENINSULA FROM KENAI TO ENGLISH BAY, ALASKA

By J.R. Riehle, R.D. Reger, and C.L. Carver

September 1977

State of Alaska

Department of Natural Resources

DIVISION OF GEOLOGICAL AND GEOPHYSICAL SURVEYS

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INTRODUCTION

The following report was prepared at the request of the Planning and Research Section of the Department of Natural Resources to summarize the present knowledge of the geology and geologic hazards along part of the eastern shore of Cook Inlet (fig. 1). It is based primarily on information gathered during two summers by two field parties supplemented by a review of published information. The section from Fox River north was investigated by R.D. Reger, assisted by J.T. Kline and C.L. Carver during August 1976 and May 1977. The section from Fox River to English Bay was investigated by J.R. Riehle, assisted by K. Emmel during May 1977. The main objectives of the field program were (1) to verify landforms identified during preliminary interpretation of aerial photographs, and (2) to determine the composition of these landforms by studying natural exposures and the walls of pits excavated by hand. The photography upon which the maps of the northern section are based was taken during September 1968 at a scale of 1:24,000. Photography for the southern section was taken during the summers of 1961 and 1975 at a scale of 1:15,840.

REGIONAL PERSPECTIVES

Seismicity

Cook Inlet and the Kenai Peninsula are situated within the well-known Circum-Pacific belt of earthquakes where seismicity is high; the Gulf of Alaska-Aleutian Range region accounts for about 7% of the seismic energy released annually throughout the world (Magoon and others, 1976). Nine great earthquakes, which have Richter magnitudes greater than 8.0, have occurred in Alaska since 1899, including the 1903 event centered in Shelikof Strait and the 1964 event centered in Prince William Sound. No great earthquakes have been recorded in the Cook Inlet region. From 1899-1974 a total of 26 earthquakes of magnitude 6.0 or greater were triggered in the Cook Inlet area, including one of magnitude 7.3 (fig. 2).

The Cook Inlet-Kenai Peninsula region is included in Seismic Probability Zone 3, an area of potential major damage from earthquakes greater than Richter magnitude 6 (Evans and others, 1972). According to Meyers and others (1976), maximum Modified-Mercalli intensities have historically ranged from VIII to IX on the Kenai Peninsula (fig. 3), indicating considerable major destruction would have occurred even to specially designed structures. This damage (both real and hypothetical) resulted from very large earthquakes centered near but not in the region, as well as from smaller earthquakes located within the region.

Prediction of future earthquakes is, at best, uncertain, especially in Alaska where few fault systems have been studied in detail and where there has been no monitoring of fault zones. Analysis of recurrence intervals indicates that the southern Cook Inlet area may be subjected to a 7.3-magnitude or greater earthquake at least once every 75 years and that an earthquake of 8.0 magnitude may occur about every 400 years (fig. 2).

Faults

The Cook Inlet basin is bounded by the Castle Mountain fault on the north and northwest, the Bruin Bay fault on the west, and the Border Ranges fault on the southeast (fig. 4). The disruption of radiocarbon-dated deposits across the Castle Mountain fault in the Susitna River valley demonstrates that fault movement occurred between 225 and 1860 years ago (Detterman and others, 1974, 1976a). Although they could not document offset of Holocene or Quaternary deposits across

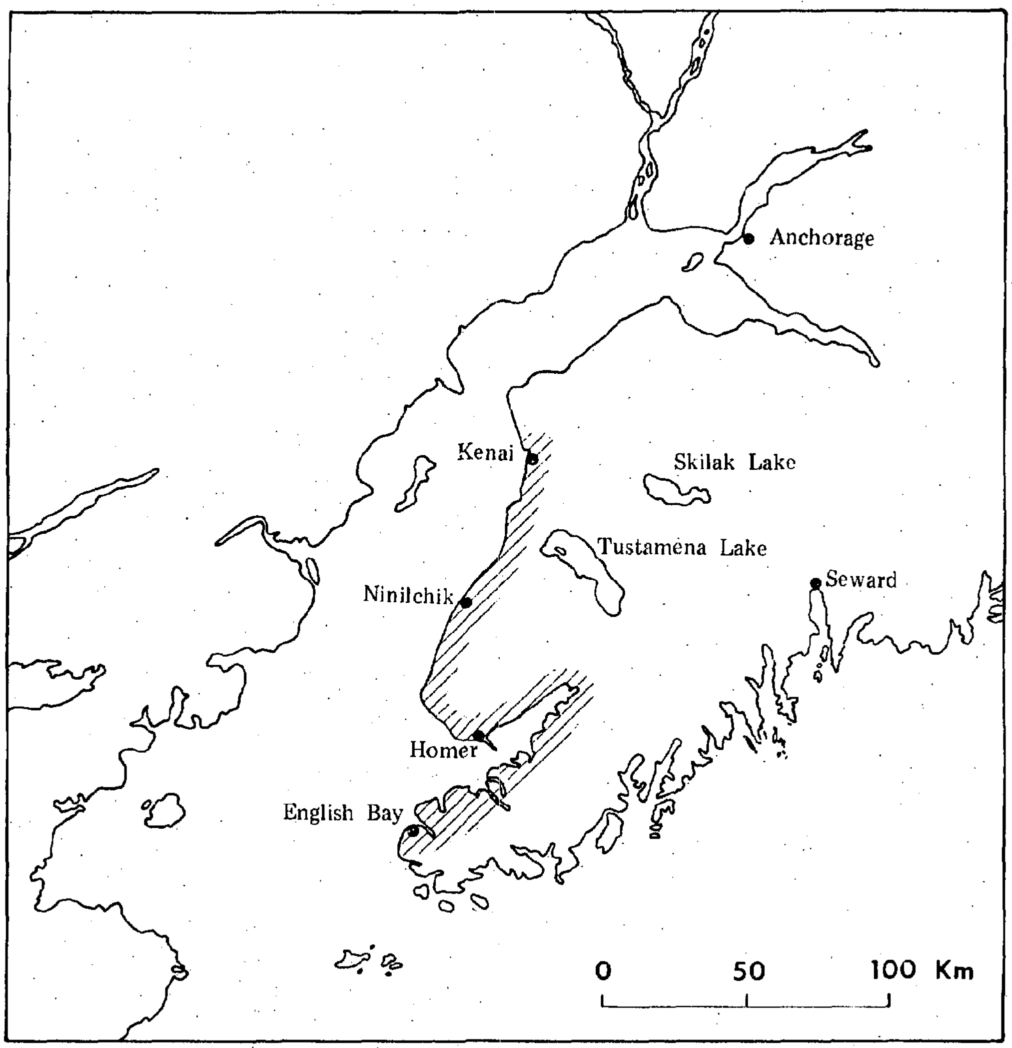

Figure 1. Study area along the coast from Kenai to English Bay, Alaska.

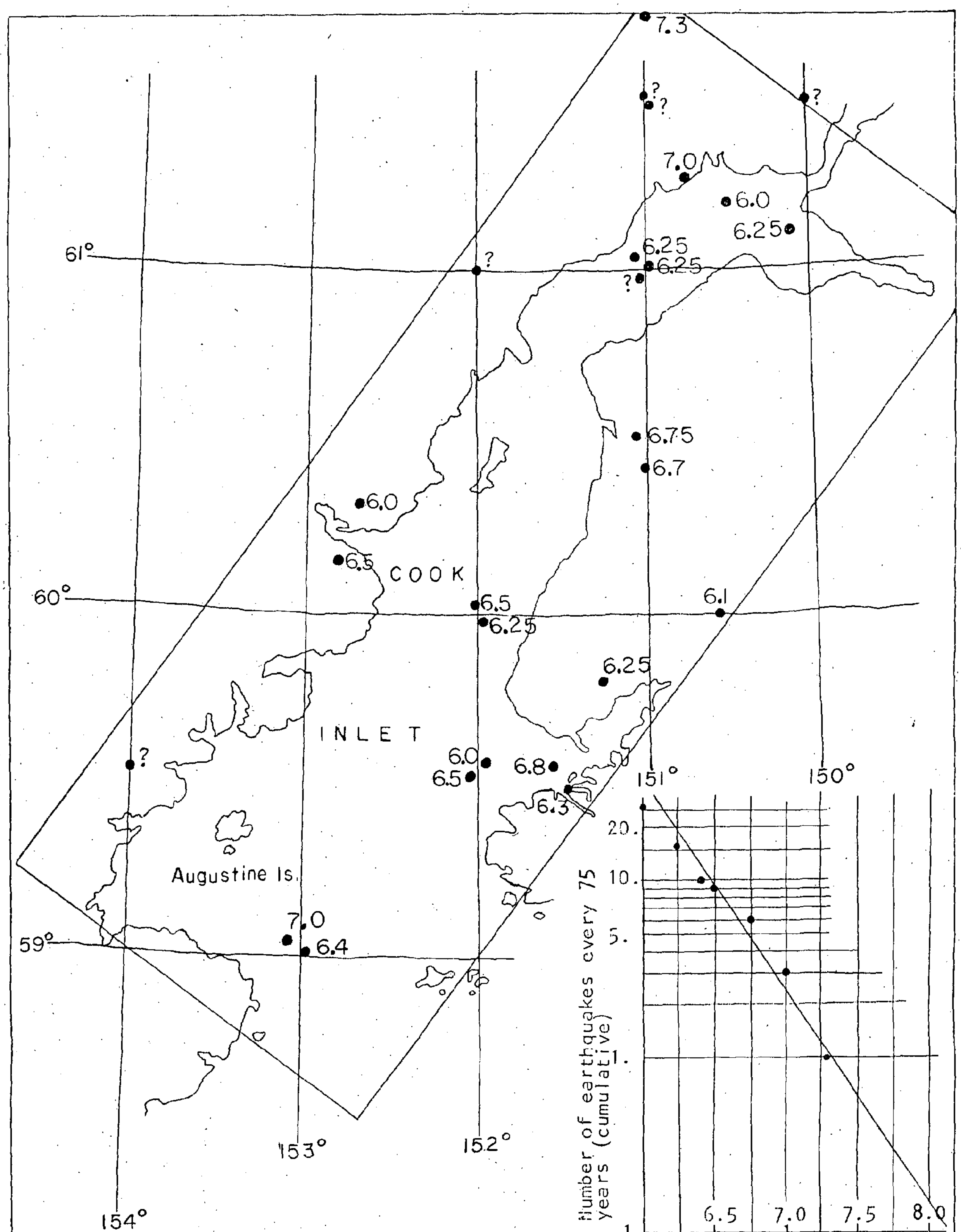

Figure 2. Locations of earthquake epicenters for the period 1899-1974 in Cook Inlet region, and recurrence interval of such earthquakes. Magnitudes are given where known. Modified from Bureau of Land Management (1976) with data from Meyers (1976). In defining the recurrence interval, earthquakes of unknown magnitudes are arbitrarily allocated equally to magnitude classes 6.0 and 6.25.

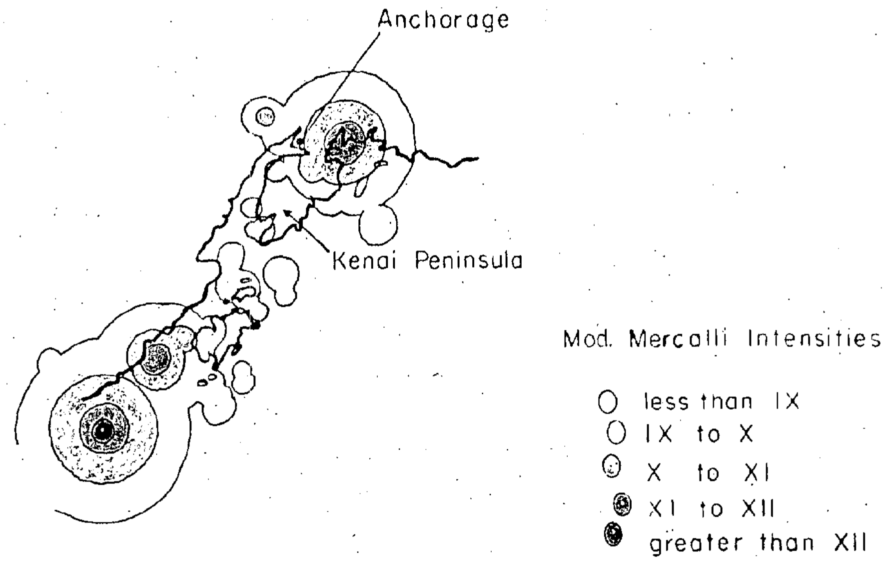

Figure 3. Projected maximum intensities of earthquakes in the Cook Inlet region for the period 1786-1974. Maximum intensities in the Cook Inlet region range from VIII to IX; MM IX is defined as "...damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; great insubstantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken." From Meyers and others, 1976. (Note: Near-fault horizontal ground motions during earthquakes have been characterized for design earthquakes along the TAPS corridor. Subject to simplifying assumptions and to uncertainties arising from limited data, the maximum horizontal accelerations are 1.2 and 1.05 times gravity (that is, 1.2 g and 1.05 g) for earthquakes of magnitude 8.0 and 7.0, respectively. The levels of horizontal acceleration which would be exceeded 10 times during an earthquake are .7 g and .55 g for magnitude 8.0 and 7.0 events, respectively. The times between first and last accelerations equal to or greater than .05 g may strongly influence the extent of damage; values are 60 seconds and 25 seconds for 8.0 and 7.0 events. Peak horizontal acceleration values and duration values decrease with distance from the fault source, at least beyond a minimum distance which is greater for larger earthquakes. Page, R. A., Boore, D. M., Joyner, W. B., and Coulter, H. W., 1972, Ground motion values for use in the seismic design of the Trans-Alaska Pipeline System: U.S. Geol. Survey Circ. 672.)

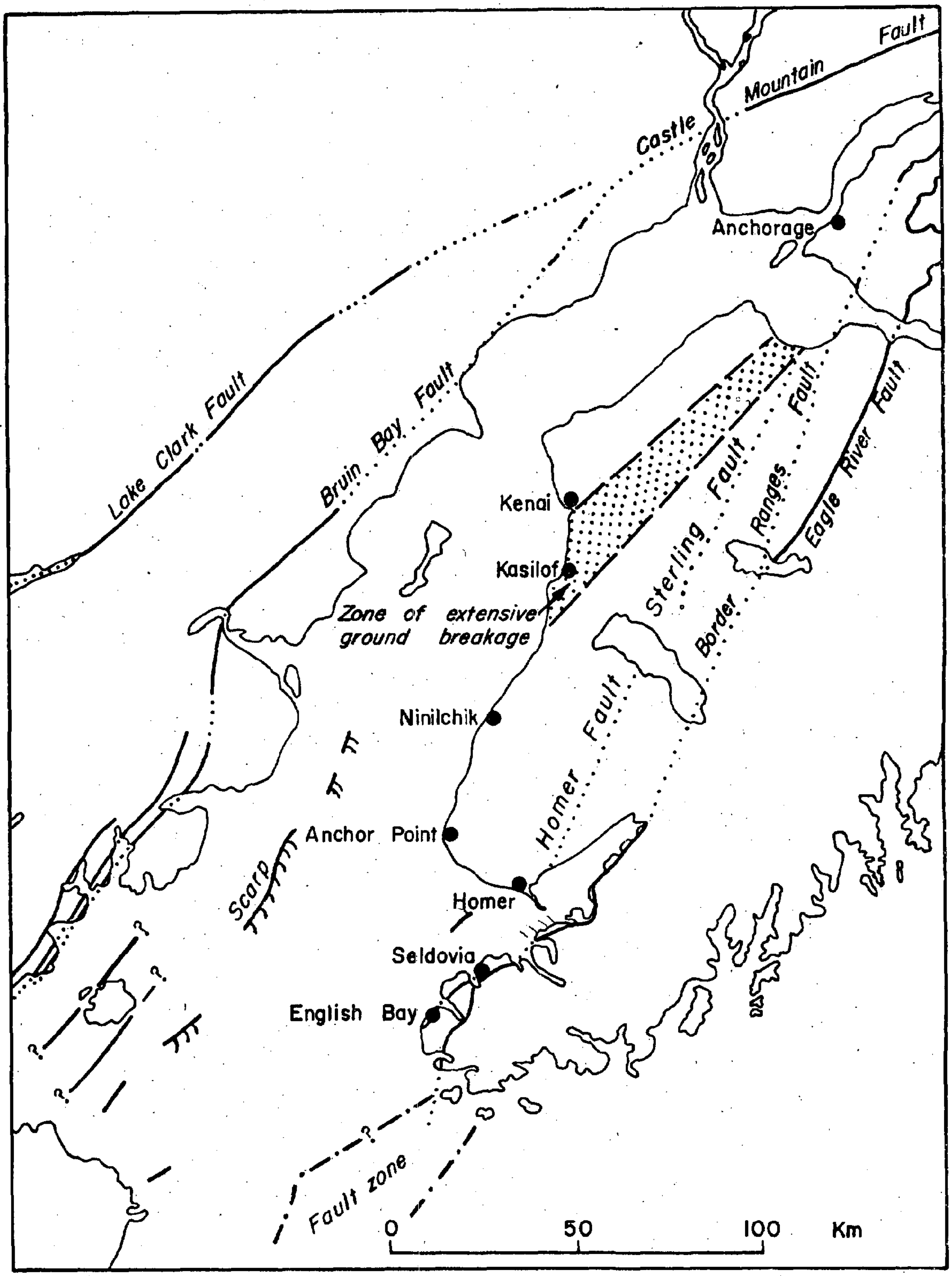

Figure 4. Major faults of the Cook Inlet area, Alaska. Concealed faults are dotted and their positions are inferred from geophysical data, well data, and projection of structural elements. Modified from Foster and Karlstrom (1967), Beikman (1974), Tysdal (1976), and Hackett (1977). Offshore faults and scarps from Bouma and Hampton (1976).

the Bruin Bay fault, Detterman and others (1976b) concluded that this major structural discontinuity is an extension of the Castle Mountain fault system and, as such, must be considered potentially active. Clark (1972) and Tysdal (1976) did not report evidence of Quaternary or Holocene activity along the complex trace of the Border Ranges-Eagle River fault system in or north of the study area. Gedney and Van Wormer (1974) demonstrated no obvious correlation of small seismic events recorded in 1972 to known faults, such as the Border Ranges fault, in the Kenai Mountains of the southern Kenai Peninsula.

Within the Cook Inlet basin numerous small, dominantly northeast- and northwest-trending faults offset beds of the Tertiary Kenai Group but not late Quaternary deposits, indicating that they are post-Tertiary in age but are not now active (pl. 1). Large subsurface faults, such as the Homer and Sterling faults, are inferred from indirect evidence and apparently are not active (fig. 4). Local subsurface faults associated with actively growing folds in the Kenai Group may be active (Kelly, 1963; Plafker and Rubin, 1967). Although such local activity is not considered capable of generating major earthquakes, it may produce significant effects in the immediate vicinity (Tysdal, 1976). An analysis of limited microearthquake data from events in the Kenai Lowland between 1972 and 1974 shows no correlation with known surface or subsurface faults (Tysdal, 1976).

Offshore faults and escarpments on the bottom of Cook Inlet have been mapped by Bouma and Hampton (1976), in particular near to the Barren Islands, at the entrance to Kachemak Bay, and near the center of Cook Inlet (fig. 4). The faults are called "small scale". Data on the nature and recency of movement along these features are preliminary and limited; any of the features could prove to be active faults.

Ground Failures

Numerous forms of ground failure, some catastrophic and others subtle, have occurred during past earthquakes in Alaska and similar responses must be anticipated during future seismic events. In 1958 a large rockslide released shortly after a Richter magnitude 7.0 earthquake hit the restricted head of Lituya Bay and generated a wave as high as 500 m (Miller, 1960). The Turnagain Heights slide in the Bootlegger Cove Clay caused extensive damage and some loss of life in Anchorage in 1964. The Bootlegger Cove Clay is composed of saturated marine clays with interbedded sand and silt lenses (Hansen, 1965; Schmoll and others, 1972). Liquefaction of the sand-silt lenses, or of the clay due to repeated shear stresses imposed by seismic shaking of long duration, occurred at depth during the earthquake, causing surface gravel and sand layers to fail due to loss of support. With the possible exception of deposits cropping out along the bluff of the coast between the mouth of the Kenai River and Cohoe (Karlstrom, 1958), thick deposits similar to the Bootlegger Cove Clay have not been recognized in the study area.

Subaerial and submarine sliding of delta fronts and glacial moraines occurred near Valdez and Seward during the Good Friday earthquake (Coulter and Migliaccio, 1966; Lemke, 1967). Small rockfalls, slumps, and slides in weakly consolidated Tertiary bedrock and till and outwash deposits exposed in steep cliffs and bluffs are fairly common along the coast of Cook Inlet. Although these areas should be considered prone to sudden mass movements, especially in the event of a large earthquake, such failures are apparently more a direct result of proximity to a free face than to the sensitive nature of the materials. Site-specific engineering evaluations, including subsurface data collection, are recommended before final decisions are made regarding bearing capacity and stability of foundation soils.

Widespread fracturing, fissuring, consolidation, and sand fountaining occurred in surficial deposits during the 1964 earthquake (Coulter and Migliaccio, 1966; Foster and Karlstrom, 1967; Lemke, 1967; Plafker and others, 1969). Some fracturing was primarily caused by progressive failure adjacent to block glides or rotational slides, but other fracturing may have been the result of movement along concealed bedrock faults. Fissures associated with sand fountaining, a surface manifestation of liquefaction, on alluvial fans and floodplains may have originated from ground-motion amplification in thick, saturated, unconsolidated sediments (Coulter and Migliaccio, 1966) and by vertical and horizontal compaction of fine-grained unconsolidated sediments (Hansen, 1965; Lemke, 1967).

Land Level Changes

The Kenai Mountains and the eastern lowlands were overridden by glacial ice as recently as about 10,000 to 12,000 years ago (Karlstrom, 1964). The earth's crust was depressed beneath these expanded glaciers until deglaciation allowed crustal rebound to reestablish gravitational (isostatic) equilibrium. Such rebound probably accounts for current uplift rates of nearly 3.96 cm/yr at Juneau (Hicks and Shofnos, 1965). Active isostatic rebound has not been reported in the lower Cook Inlet area, but the effects of this process may be masked by other processes such as eustatic sea-level changes or regional tectonics.

The entire study region subsided relative to sea level during the 1964 earthquake. Plafker (1969) showed isobase contours of relative subsidence that trend approximately N30E through Kachemak Bay; a 1.22-m subsidence contour passes through the mouth of Tutka Bay. Subsidence was greater to the east (1.83 m at the entrace to Port Dick) and less to the west (0.61 m at Anchor Point). In summarizing available evidence, Plafker (1969) concluded that Kachemak Bay and the west side of the southern Kenai Peninsula are part of a larger area that has tectonically subsided at least since the most recent deglaciation. The available evidence indicates that parts of the study area have undergone about 6.1 m of submergence relative to sea level during the past 2,000 to 3,000 years, including about 1.22 m of regional subsidence in the 1964 earthquake. Presumably such net subsidence is a reflection of crustal strain release during earthquakes. If so, it is likely that the study area will continue to undergo net subsidence during future large earthquakes.

Earthquake Tsunamis and Seiches

Tsunamis are gravitational sea waves generated by any large-scale, short duration disturbance of the ocean floor, including shallow submarine fault movements, submarine landslides, subsidence, and volcanic eruptions. The 1964 tsunamis that affected Cook Inlet were not generated by submarine faulting or sliding within the basin, but were triggered about 161 km seaward of the Barren Islands near the edge of the continental shelf. Damage in the Cook Inlet area was not widespread, although the largest of several seawaves at Seldovia was 7.9 m (above mean lower low water?) (Plafker and others, 1969) and the Homer Spit was inundated by a 1.1 m high wave (Waller, 1966). The lack of tsunami production in Cook Inlet during the 1964 earthquake may be due to the absence of nearshore, glacially oversteepened bedrock slopes, to the apparent absence of large failures of delta deposits, or to the low magnitude and short duration of seismic shaking.

Outside Cook Inlet severe damage was sustained in the Kodiak Islands where tsunami runups were as high as 12.2 m above the existing tide levels; at Kodiak City the highest wave coincided with and crested 7 m above the high-tide level

(Plafker and Kachadoorian, 1966; Kachadoorian and Plafker, 1967). Submarine landsliding of parts of a glacial end moraine in Port Valdez probably produced waves from 10.7 to 51.8 m high (Plafker and others, 1969). Submarine failure of fan delta deposits along the Seward waterfront and at the head of Resurrection Bay during the Good Friday earthquake triggered local tsunamis that caused considerable damage (Lemke, 1967).

Seiches are standing waves that travel back and forth in an enclosed or semi-enclosed basin with a period dependent on the depth and size of the water body. Seiches may be caused by changes in atmospheric pressure aided by winds, tidal currents, and earthquakes. They were reported on Tustumena, Skilak, and Kenai Lakes and on Bradley River at the head of Kachemak Bay during the 1964 earthquake (Waller, 1966; McCulloch, 1966; McGarr and Vorhis, 1968). In restricted and shallow portions of Kenai Lake seiche waves reached heights of 6 to 9 m (McCulloch, 1966).

Vulcanism

A line of recently active volcanoes extends up the western side of Cook Inlet from Mt. Douglas to Hayes Volcano (fig. 5). This group of six volcanoes is the northern segment of a belt of volcanoes studding the Aleutian arc (Coates, 1950). The volcanoes are predominantly andesite, a composition that characteristically produces relatively violent eruptions. They are classified as quiescent to active and potentially eruptive (table 1). Four eruptive episodes have occurred during the past 25 years and numerous buried ash layers record a history of many major eruptions.

The potential local hazards associated with violent volcanic eruptions on Cook Inlet include severe blast effects, nuées ardentes, pyroclastic flows, lava flows, volcanic mudflows (lahars), turbulent clouds of ash and hot gases, lightning discharges, corrosive rains, flash and outburst floods, earthquakes, and tsunamis. Because the volcanoes are situated along the western side of Cook Inlet, the eastern shore will be indirectly affected by volcanic eruptions. Special concern must be devoted to the effects of tsunamis on developments along the coast from Kenai to English Bay. The 1883 eruption of Augustine Volcano produced a large mudflow and nuées ardentes which hit the inlet and generated a sea wave 8 to 9 m high. This sea wave struck Port Graham 85 km to the east 25 minutes later (Dall, 1884, in Kienle and Forbes, 1977). Fortunately the incident occurred at low tide or significant damage and perhaps loss of life could have resulted. Another tsunami may have been generated by the 1901 eruption of Augustine Volcano (Cox and Parraras-Carayannis, 1976). Augustine Volcano is particularly dangerous because it is surrounded by marine waters. Krakatoa, a small island similarly situated in the Dutch East Indies, also erupted in 1883, but with a series of extremely violent explosions produced by the vaporization of sea water entering the magma chamber through cracks in the walls. About 36,000 people living on the lowlands of neighboring Java and Sumatra drowned during inundations by tsunamis generated by the explosions (Bolt and others, 1975). The shores and flats bordering Cook Inlet are potentially exposed to similar inundations produced during explosive eruptions of Augustine Volcano. Becuase of this potential danger, Augustine Volcano has been continuously monitored since 1970 by the Geophysical Institute of the University of Alaska, Fairbanks (Kienle and Forbes, 1977).

Other, less dangerous, indirect hazards of vulcanism are ashfalls and acid rains. Ash from the 1912 eruption of Mt. Katmai covered parts of Kodiak Island to depths of more than 0.4 m and corrosive rains fell on Seward and Cordova,

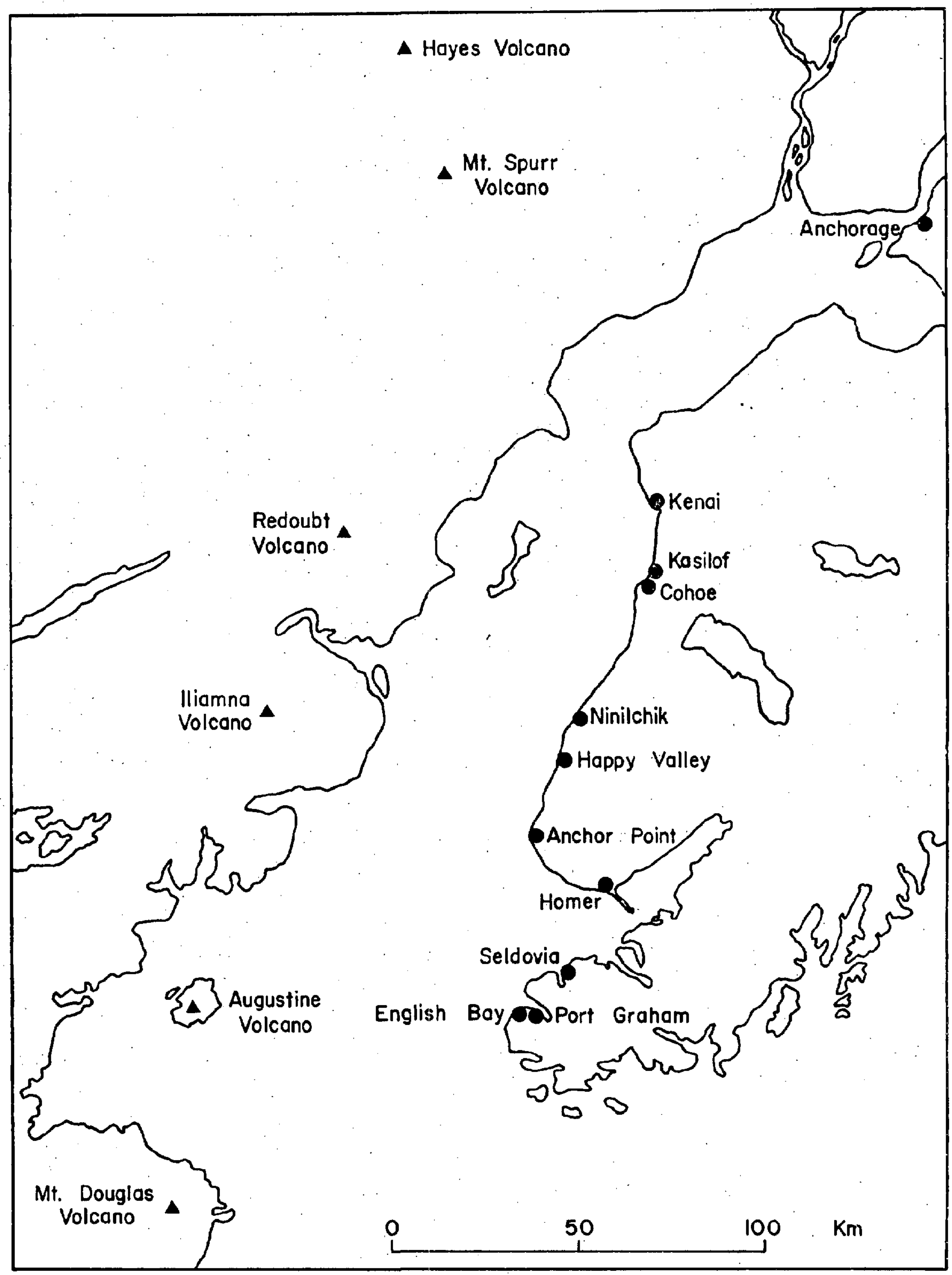

Figure 5. Volcanoes of the Cook Inlet area, Alaska. Modified from Evans and others (1972) and Miller and Smith (1976).

Table 1. State of Volcanic Activity in the Cook Inlet Area (Wilcox, 1959; Evans and others, 1972; Miller and Smith, 1976).

Volcano	Last Eruption	Present State
Mt. Douglas	None in historic time	Quiescent
Augustine	1976	Active and potentially eruptive
Iliamna	1867	Active but quiescent
Redoubt	1966	Active and potentially eruptive
Mt. Spurr	1953	Active but quiescent
Hayes	None in historic time	Quiescent

painfully burning people, damaging vegetation, and corroding exposed metal (Wilcox, 1959). The 1953 eruption of Mt. Spurr deposited ash on the outskirts of Anchorage that damaged aircraft and its removal required considerable expenditure of money and labor. Airborne measurements of effluents from Augustine Volcano in February 1976 indicate the ash was erupted at a rate of about 10^5 kg/s during brief intervals and the ash cloud attained a height of 5.3 km (Hobbs and others, 1977). Depending on wind conditions, ash clouds could force cessation or diversion of aircraft flights during eruptions, even as far away as the eastern shore of Cook Inlet.

NORTHERN SECTION: KENAI TO FOX RIVER

The northern section is a strip approximately 158 km long and 1 to 3 km wide (pl. 1). It includes parts of 9 quadrangles: Kenai A-4, A-5, B-4, C-4, and Seldovia C-4, C-5, D-3, D-4, and D-5. The area includes the settlements of Kenai, Kasilof, Cohoe, Clam Gulch, Ninilchik, Happy Valley, Anchor Point, and Homer.

Geology

Bedrock

The Kenai Group is a sequence of middle to late Tertiary fine-grained sedimentary rocks comprising the only bedrock along the coast from Kenai to Fox River. The units crop out almost continuously in the precipitous wavecut cliffs and steep walls of stream canyons from Fritz Creek northeast to Fox River and from Happy Creek north to about 11 km south of the Kasilof River mouth (pl. 1). Less continous exposures occur from Fritz Creek north to the Anchor River and in steep walls of the valleys of Anchor River, Happy Creek, Deep Creek, and Ninilchik River.

The sequence consists of at least 1500 m of moderately to weakly indurated, locally conglomeratic sandstone with interbedded siltstone, claystone, and coal.

The proportion of sandstone increases northward and the number and thickness of coal beds and the quality of the coal decreases. The coal is ranked as lignitic to subbituminous. Coal beds are generally lenticular, ranging in thickness from 1 to 2 m; at least 30 different beds are recognized (Barnes and Cobb, 1959). Many former coal beds have been burned, baking the adjacent rocks a distinctive brick orange color.

The Kenai Group occupies the southern part of the large structure comprising the Cook Inlet basin. Superimposed on the general basin structure is a series of broad, gentle folds striking generally northeast. The limbs of these folds generally dip less than 10^{o}, except in the vicinity of faults where dips up to 20^{o} have been measured (Barnes and Cobb, 1959). Numerous high-angle faults offset bedding from a few cm to nearly 25 m. Seismic investigations by the USGS indicate that stratigraphic and structural relationships continue offshore where anticlines and synclines have wavelengths of 8 to 12 km (Magoon and others, 1976).

Surficial Deposits

Bedrock is overlain by a widespread complex of unconsolidated deposits laid down as a direct or indirect consequence of glaciation or by subsequent stream activity (Karlstrom, 1964) (pl. 1). The most extensive deposits are glacial till and organic swamp deposits. Outwash sand and gravel (coalesced fan deltas) are exposed in the coastal bluffs from Cohoe north to Kenai (Karlstrom, 1958). Outwash and meltwater channel fills locally bury or are inset into glacial drift south of Cohoe, particularly near major stream valleys. Stream floodplains are underlain by granular alluvium and are bounded by discontinuous fluvial terraces. Sand and gravel beaches separate wavecut cliffs and bluffs from inlet waters along the entire coast and tidal flats are extensive between Homer Spit and Fox River. Alluvial and colluvial-alluvial fans are especially well developed in the vicinity of Homer where they are derived from rapid erosion of the Kenai Group exposed in the glacially steepened slopes north and northeast of town. Various forms of colluvium (including a large rockfall southeast of Bluff Point near Homer), slumps, and mudflows are scattered along steep coastal bluffs and on the walls of stream valleys throughout the study area. Wind-blown silt (loess) forms a blanket 0.1 to 0.4 m thick almost everywhere except on beaches and tidal flats. The thickness of the surficial deposits varies from less than 1 m to more than 50 m.

No samples were collected for granulometric analyses, but estimates of the grain-size composition of each landform were made in the field. These field observations are the bases for deriving the geologic materials map (pl. 2) and the summary of the potential availability of various construction materials (table 2). Precise evaluations of the economic viability of specific gravel and sand deposits will require more detailed studies of the physical properties of each deposit, including areal extent, thickness of overburden, thermal state of the groun, and depth to the water table, was well as consideration of such economic factors as general availability of gravel and sand in the area, haul distance from source to job site, type of transportation available, and demand for the product.

Geologic Hazards

In addition to the seismically related and volcanic hazards discussed in the section on regional perspectives, major geologic hazards in the northern section may result from (1) ground failure, (2) coastal erosion, and (3) flooding.

Table 2. Summary of potential availability of various construction materials in geologic-materials map units, east shore of Cook Inlet from Kenai to Fox River, Alaska.

Map Unit	Composition	Probability of locating good sources of - - -*: Gravel and sand	Sand	Mixed coarse- and fine-grained material	Clay	Crushed aggregate	Riprap armor rock	Building stone	Incorporated geologic units
I	Sand and gravel	Good	Good	Poor	Nil	Good	Nil	Nil	Floodplain deposits, terrace alluvium; fills in abandoned meltwater channels; kame-esker complexes; outwash alluvium; beach deposits.
II	Chiefly gravel and sand	Moderate	Moderate	Poor	Nil	Moderate	Nil	Nil	Granular alluvial fans; colluvial-alluvial fans.
III	Chiefly sand	Moderate	Good	Poor	Poor	Nil	Nil	Nil	Tidal-flat deposits.
IV	Chiefly silt and clay	Poor	Poor	Nil	Moderate	Nil	Nil	Nil	Lake deposits.
V	Chiefly mixed coarse- and fine-grained material	Poor	Poor	Good	Poor	Poor	Nil	Nil	Glacial till; colluvium; landslides; mudflow deposits; alluvial fans.
VI	Chiefly peat	Nil	Nil	Nil	Poor to nil	Nil	Nil	Nil	Swamp deposits.
VII	Chiefly weakly indurated sandstone with interbedded siltstone and claystone	Nil	Moderate to good	Nil	Moderate	Nil	Nil	Nil	Kenai Group.

*The imprecise terms "good," "moderate," "poor," and "nil" are purposely used to indicate the relative probability of locating good deposits of each construction material in the various map units. No definite values are assigned to each term, but they may indicate a probability of 80% or more for "good," 30% to 80% for "moderate," less than 30% for "poor," and essentially zero chance for "nil."

Ground Failure

The largest slope failure along the coast in the northern section is the 4.7-km long rockfall below Bluff Point near Homer (pl. 1). This massive fall of weakly to moderately consolidated Tertiary sandstone and siltstone occurred more than 1555 ± 135 years ago, according to radiocarbon dating of alluvial-colluvial deposits partially capping the feature. The considerable degree of post-failure modification indicates that the fall may have happened shortly after deglaciation of the area at the end of the Skilak Stade of the Naptowne Glaciation before 9,000 years ago and perhaps as early as about 12,000 years ago (Karlstrom, 1964). Most of the body of the rockfall appears to be stabilized, although the fan deposits on top of the southern 60 to 400 m of the rockfall have been rotated northward by secondary slumping in response to wave erosion at the toe of the sea cliff or perhaps seismic shaking during the past 1160 ± 120 years. During the 1964 earthquake fissures as deep as 6 m developed parallel to the 230-m high headwall as far as 30 m back from the edge (Waller, 1966). These cracks pose a serious slope stability hazard if surface or near-surface water enters them. Other potential rockfall hazards are promontories extending out from precipitous bluffs and cliffs weathered in the Kenai Group north and north-east of Homer (pl. 1).

In addition to the southern portion of the Bluff Point rockfall, numerous small- to moderate-sized slumps are present along the coastal bluff and in steep canyons; one of the largest single slumps is at the mouth of McNeil Canyon (pl. 1). These rotational failures have occurred in both the Tertiary bedrock and the overlying glacial till. The times of failure are unknown but most are fresh. The triggering mechanism in most cases is probably undercutting of the toe of the slope by wave and stream erosion. Another potential cause is seismic shaking, which induces liquification in some saturated soils, but Waller (1966) and Foster and Karlstrom (1967) documented surprisingly few slumps resulting from the 1964 earthquake in spite of the high intensity and long duration of the shaking, the extensive high bluffs, and the unconsolidated to weakly consolidated character of the bedrock and overlying deposits.

Other common types of ground failure include slides, flows, surface raveling on oversteepened slopes, subsidence, and mudflows. Several small slides and earthflows were triggered by the 1964 earthquake along the coast and on the steep walls of stream valleys (Waller, 1966; Foster and Karlstrom, 1967). Two submarine slides occurred near the tip of the Homer Spit; one dropped the seawall of the small boat harbor beneath the waters of Kachemak Bay. The Homer Spit subsided up to 1.8 m and ground cracking occurred during the Good Friday earthquake in response to tectonic movement, compaction, and lateral spreading. At the same time differential compaction or removal of underlying materials by groundwater eruption caused extensive cracking of the ground in a linear belt from Kasilof to Chickaloon Bay (fig. 4). Foster and Karlstrom (1967) concluded that this zone of ground breakage may be related to movement along a subsurface fault system, but Tysdal (1976) disagreed, pointing out the lack of discernible aftershock activity within the belt and the lack of corroborating aeromagnetic and gravity data. Ancient collapse pits and linear troughs record previous episodes of ground cracking and groundwater eruption in the same area and similar responses should be expected during major earthquakes in the future. Mudflows are a serious hazard during rainy seasons in the steep canyons cut into the Kenai Group and in the area of the mouths of these canyons.

Coastal Erosion

Most of the coast from Kenai to Fox River is receding at various, presently unquantified rates in response to wave attack. This erosion has resulted in loss of property and the destruction of buildings or facilities constructed near the edge of the coastal bluff. Erosion is a serious problem, particularly where the bank is composed of peat or unconsolidated granular deposits as in the area of Miller's Landing east of Homer. The present cycle of erosion apparently began after the 1964 earthquake when the western Kenai Peninsula subsided relative to sea level (Stanley, 1968). Retreat will continue until beaches are sufficiently built up to protect banks from wave attack.

Flooding

Surface waters have been monitored on the Kenai Peninsula for only a very short period of time. As of 1970 complete data were collected by the USGS only on the Kenai River, Ninilchik River, and Anchor River and crest gages were maintained on Kasilof River, Diamond Creek, and Fritz Creek (Childers, 1970). Floodcrest discharges for maximum known floods vary from 650 to 30,000 cfs (table 3). Flood discharges have been calculated for various recurrence intervals up to 25 years for the Kenai, Kasilof, and Anchor Rivers and up to 10 years for Ninilchik River (table 4). These calculations incorporate such factors as area of the drainage basin, swamps, and lakes, mean annual precipitation, and precipitation intensity.

The Kenai and Kasilof Rivers are subject to periodic catastrophic flooding resulting from the abrupt release of waters impounded in glacier-dammed lakes (Post and Mayo, 1971). During these events the volume of water suddenly released may be many times greater than nonoutburst floods. At these times flooding may result in serious damage and loss of life, especially if the water level is already high or the stream is frozen or partially frozen. For example, during a period of very cold weather in January 1969 the drainage of an unnamed lake held in by Skilak Glacier produced a large ice jam in the Kenai River that caused inundation of low areas and considerable ice-shove damage (U.S. Army Corps of Engineers, 1973). Prediction of outburst events is often difficult because the number and size of ice-dammed lakes vary greatly each year and because many lakes are partially or completely subglacial; outbursts are not simply related to seasonal changes.

Property damage from inundation, channel erosion, and deposition should be expected on all floodplains and some of the lower terraces in the study area (pl. 1). Maps of areas subject to inundation by 25- and 50-year floods along the lower Kenai River have been prepared by the U.S. Army Corps of Engineers (1967; 1973).

SOUTHERN SECTION: FOX RIVER TO ENGLISH BAY

The southern section comprises a coastal strip which extends inland generally to bedrock ridgelines, and from Sheep Creek and Fox River on the north to English Bay on the south (pl. 3). Topographic base maps are parts of the Seldovia B-4, B-5, B-6, C-3, C-4, C-5, and D-3 quadrangles. Established communities in the southern section are Seldovia, Port Graham, and English Bay.

Table 3. Maximum known floods for four major streams entering eastern Cook Inlet between Kenai and Fox River, Alaska (Childers, 1970).

USGS station no.	Locality	Years of record	Date	Gage height (ft.)	Discharge (cfs)
2663	Kenai R at Soldotna	4	10-15-69	12.20	30,000
2420	Kasilof R near Kasilof	20	09-14-57	7.90	12,300
2416	Ninilchik R at Ninilchik	6	06-02-64	4.46	650
2400	Anchor R at Anchor Point	14	05-08-63	6.36	3,030

Table 4. Estimated flood discharges at various recurrence intervals for four major streams entering eastern Cook Inlet between Kenai and Fox River, Alaska. Based on all records available as of September 30, 1968 (Childers, 1970).[1]

USGS station no.	Locality	Drainage area (mi^2)	Period of record (years/dates)	Flood discharges for various recurrence intervals (cfs)[2] Q_2	Q_5	Q_{10}	Q_{25}
2663	Kenai R at Soldotna	2,010	1(1965-1966)	25,500	32,000	36,300	40,600
2420	Kasilof R near Kasilof	738	20(1948-1968)	8,130	9,550	10,500	11,800
2416	Ninilchik R at Ninilchik	131	6(1962-1968)	470	565	622	------[3]
2400	Anchor R at Anchor Point	226	14(1952-1966)	1,880	2,360	2,680	3,080

[1] Values for the Kenai River at Soldotna are taken from a tentative peak discharge frequency curve based on only one year of record and correlation of drainage basin relationships with the Cooper Landing station on the Kenai River (U.S. Army Corps of Engineers, 1967).

[2] Recurrence interval is defined as the average interval of time within which the given flood discharge will be exceeded once (Childers, 1970). For example, Q_{10} is the peak discharge for a 10-year average-recurrence interval and there is a 10% chance that the annual flood in a given year will exceed Q_{10}. For a 5-year average-recurrence interval, there is a 20% chance that the annual flood will exceed Q_5 in a given year. Standard errors of Q_2, Q_5, Q_{10}, and Q_{25} are 80%, 80%, 81%, and 72%, respectively.

[3] The record is too short for prediction of the 25-year flood.

General Setting

Kachemak Bay is a glacial fiord, eroded along the contact of relatively soft Tertiary rocks (sedimentary) which underlie the Kenai Lowlands and relatively hard pre-Tertiary rocks (sedimentary and metamorphic) which underlie the Kenai Mountains. Glacial ice occupied the bay at least as recently as 10,000 B.C. Northwest-trending valleys enter Kachemak Bay from the Kenai Mountains; most (such as Sadie Cove and Tutka Bay) have such attributes of classical fiords as a steep-walled, U-shaped profile and deep marine waters. Other bays have shallower water (for example, Seldovia Bay) and some are drowned only at the mouth (for example, English Bay), but all are glacially eroded. Glaciers still remain at the heads of the major valleys from Tutka Bay to the north edge of the southern section.

The absolute ages of the most recent major glacial advance(s) in the southern section are not known. Karlstrom (1964, p. 20) suggests by implication that the Homer Spit may have formed at an ice terminus between 10,000 and 7,500 B.C.; if so, it is reasonable to expect that Alpine glaciers in the major valleys of the southern section would also have been in advanced positions at about that time. However, Karlstrom proposes several relatively minor glacial advances during the period after 7,500 B.C. for the northern Kenai Peninsula, and most glaciers occupying major valleys in the southern section probably advanced to some extent at similar intervals. None of the existing glaciers are presently advancing.

The coastline of the southern section is, overall, one of submergence. Glacial erosion produced steep-walled, U-shaped tributary valleys; these valleys were inundated by rising sealevel following recession of the valley glaciers. In addition to sealevel rise, Plafker (1969) concludes that Kachemak Bay and the west side of the southern Kenai Peninsula are part of a larger area which has experienced regional (tectonic) subsidence at least since the most recent deglaciation. Evidence of subsidence includes the classic submergent morphology (drowned cirques) on the outer (southeastern) coastline of the Kenai Peninsula, as well as drowning middens in several Kachemak Bay sites. The middens are described by De Laguna (1934) from Kasitsna Bay, Ismailof Island, and Yukon Island; she concludes that submergence at the Yukon Island site was 4.2 m since initial occupation of the site (De Laguna, 1934, p. 28). Pieces of caribou antlers were dated from each of 2 different levels at this site (Rainey and Ralph, 1959) and the ages are presented by Plafker (1969, p. I-54) to give an implied <u>average</u> rate of subsidence at the site over the past 2700 years of 2.24 m per 1000 years (datum is 1965 sea level). However, in a preface to her second edition in 1975, De Laguna (p. ix) emphasizes that the samples used for radiocarbon analysis were contaminated. Consequently, any attempt to quantify the average rate of net subsidence of the southern section for the past few thousand years is attended by uncertainty.

Parts of the coastline are presently building out by construction of fan-deltas at the mouths of major rivers (McKeon Flats, Greywingk Creek, Mallard Bay, and at the heads of fiords); in such areas the net rate of sedimentation has been greater than the rate of submergence, although seaward portions of the fan-deltas are periodically flooded because of regional subsidence. Nearly everywhere else in the southern section, the coastline consists of seacliffs cut by wave erosion in bedrock. Seastacks and seacaves attest to the dominance of wave erosion over deposition (for example, at the entrance to Seldovia Bay).

Beach materials in the southern section are mainly pebbles and cobbles, commonly mixed with sand; waves have constructed spits and tombolos of these materials along the outer coastline (for example, Seldovia Bay). The implied direction of net littoral drift along the outer coastline is from the southwest. Barrier spits and beaches offshore of some fan-deltas provide protection from waves (for example, China Poot Bay). Barrier beaches at some small lagoons (for example, Selenie Lagoon and English Bay) consist in part of rounded boulders as much as 1 to 2 feet in diameter; probably these boulders are the wave-eroded remnants of glacial drift deposits (bay-mouth moraines?). No data exist on the sources of littoral-drift sediments along the outer coastline, but the association of wider beaches with seacliffs cut in soft Tertiary rocks suggests that much of the material is locally derived by mass wasting of material comprising the seacliffs. Intertidal and beach deposits from Neptune Bay to the head of Kachemak Bay probably are derived chiefly from sediments transported by the larger rivers, which consist in part of glacial meltwater.

Bedrock

Bedrock is widely exposed in the southern section and consists mainly of slightly metamorphosed sedimentary and volcanic rocks, crystalline metamorphic rocks, and minor amounts of intrusive igneous rocks. Lithologies are chiefly slate, greywacke, volcanic flows (basalts), and volcanic tuffs and breccias, with lesser amounts of chert, limestone, schist, and marble. Sedimentary ages range from Triassic to Cretaceous; the crystalline metamorphic rocks were metamorphosed in Late Triassic or Early Jurassic time. Deformation ranges in degree from slight (for example, sedimentary rocks exposed at the southwest headland, Seldovia Bay entrance) to intense (schists, and some interlayered cherts, tuffs, and flows). (See Forbes and Lanphere, 1973; Beikman, 1974.)

In addition to pre-Tertiary rocks, Tertiary rocks are exposed locally along the outer coastline southwest of Tutka Bay. The Tertiary rocks consist of weakly to moderately indurated siltstones, sandstones, conglomerates, and local, relatively minor coal beds. Faults with apparent maximum displacements on the order of a few meters were seen cutting the Tertiary rocks near Seldovia Point; no such faults were observed to clearly offset the overlying glacial deposits, and the faults are tentatively considered to be inactive. Where observed, bedding planes in Tertiary rocks were within a few degrees of horizontal.

Sources of large riprap (armor riprap) are limited in the study area. Tertiary sedimentary rocks are relatively poorly indurated and susceptible to weathering. Pre-Tertiary rocks are either deformed, or pervasively fractured and jointed, or are susceptible to parting along bedding planes. Consequently, identification of specific rocks suitable for use as armor riprap requires detailed site inspections. Field time during the present study was not adequate for comprehensive inspections. In general, armor riprap has been obtained from the headland at the entrance to Sadie Cove (meta-volcanic rock) and from Grey Cliff point near Seldovia (impure marble). The Sadie Cove tidewater site, and a tidewater site at Halibut Cove (igneous intrusive) were identified as potential riprap sources by State of Alaska, Department of Highways personnel during a field investigation in 1968. The Grey Cliff site was briefly inspected by U.S. Army Corps of Engineers' personnel in 1965. According to Mr. Glen Greeley, Corps of Engineers (personal communication, August 1977), no other feasible tidewater sources were identified by Corps' personnel during a coastal reconnaissance in the southern section.

Surficial Deposits

The major surficial deposits recognized in the southern section are: 1) glacial drift, comprising till and stratified drift (outwash); the drift is generally thin, less than 2 or 3 m thick, except along the outer coastline in the southern part of the map area and along the southeast side of Sheep Creek; 2) marine deposits, mainly sand-shingle beaches and deposits of intertidal flats and deltas; 3) alluvial fan and floodplain deposits of active rivers and glacial outwash deposits; 4) a large rotational block landslide southeast of Sheep Creek, as well as numerous smaller slides, falls, and debris flows in bedrock and unconsolidated deposits near unconfined steep surfaces elsewhere in the southern section.

Relatively thin deposits of drift are included in Unit Qd; thicker drift deposits which have been observed in bank or roadcut exposures are shown as Unit Qdo (pl. 3). Glacial outwash deposits which are morphologically separable from drift are shown as Unit Qo, which includes valley train deposits in valleys with apparently underfit streams, vegetated terraces above present valley floodplains, and floodplains of active streams which presently drain glaciers. Narrow channels with no apparent streamflow and no obvious drainage area are shown on plate 3 by a wide arrow. These channels are inferred to have been meltwater drainages which eroded at former glacier margins; little or no fill is visible on air photos, although the channels may locally contain minor amounts of sand, gravel, and boulders.

Marine deposits are shown on plate 3 as deltas (Qid), intertidal flats (Qif), and beaches (Qib). Each of the three types of deposits is subdivided as to presence (example: Qidv) or absence (example: Qida) of vegetative cover. Vegetative cover does not imply that a deposit is no longer within reach of seawater; beaches may be overwashed only infrequently by storm waves at highest tides and so support vegetation, and salt-tolerant plants may grow in tidal marshes in the upper part of the intertidal zone. The "a" and "v" distinction for marine deposits should be used only as a general guide to relative frequency of marine inundation.

Large alluvial fans with relatively low surface gradients are shown on plate 3 by the symbol Qaf. Smaller fans with steeper gradients are represented by Qff, and floodplains are shown by the symbols Qal and (for the larger rivers presently draining glaciers) Qo.

Deposits resulting from mass movements are shown by the symbols Qct (talus deposits) and Qcl (landslide deposits). Talus deposits originate by individual rock falls, that is, "one piece at a time". Landslides involve mass movements of larger amounts of material; a variety of slides, falls, and flows will break apart during movement, producing a heterogeneous and nonsorted deposit. Other slides occur by rotational (slump) or lateral (translatory) movement of material along a well-defined plane of failure, and little or no disruption of the moving mass occurs. Several landslides tentatively classified as slumps are recognized in the southern section. These slides are shown by symbols "Qcl/x", where "x" is given as the map symbol for the original deposit involved in the landslide. Other landslides in the southern section are shown only by the symbol Qcl; these landslides are mainly rockfalls or rockslides (including the large rockfall/slide on the terminus of Greywingk Glacier), and smaller deposits tentatively classified as debris flows or earthflows.

Sand and gravel deposits potentially suitable for commercial extraction occur in a variety of ways: as marine deposits along beaches and deltas, as river deposits in channels, floodplains, and large alluvial fans, and as glacial outwash and stratified drift. The largest deposits are in beaches and in floodplains and alluvial fans of the larger rivers. Exploitation of such large deposits will be hampered by seawater and shallow groundwater. Lesser volumes are available in glacial outwash deposits, and in stratified drift which occurs locally within glacial drift. Sand and gravel deposits are shown on plate 4; in delineating the deposits, no attempt was made to classify them by potential feasibility. Feasibility depends on many factors, including physical characteristics of the sand and gravel and suitability for particular uses, size of the deposit, ease of extraction, and distance from the site of intended use. Consequently, plate 4 should be used only as a general guide for future feasibility studies once specific needs have been identified.

Geologic Hazards

The main geologic hazards in the southern section, as identified during the course of the present study, are outlined below.

Mass Movements

Rockfalls are rapid movements of large rock masses on very steep slopes essentially by falling; deposits of two rockfalls are tentatively identified along the north shore of Halibut Cove and on the Greywingk Glacier near the terminus (Qcl, pl. 3). (The Greywingk Glacier rockfall apparently involved some lateral movement onto the glacier, and so may be more properly termed a combination fall/slide.) Debris flows and earthflows are slow to moderately rapid movements of "slurries". The slurry results from the addition of water to soil, weathered bedrock, and/or unconsolidated surficial deposits. Motion may be started in a variety of ways; commonly, slumping of saturated surficial deposits or rapid erosion during high runoff are generating mechanisms. Deposits of debris flows or earthflows are tentatively identified at the foot of slopes covered by glacial till and outwash at the northeast corner of Kachemak Bay and nearby along Sheep Creek (Qcl, pl. 3). Also, many alluvial fans (especially small steep fans, unit Qff on plate 3) probably consist in part of poorly sorted debris flow or mudflow deposits. Rotational landslides (slumps) are characterized by ground failure along one (or more) well defined planes, so that commonly a visible scarp results as the slide block moves down and laterally. Rotational landslides are tentatively identified on the slopes southeast of Sheep Creek near Kachemak Bay (local stream erosion could cause renewed local or massive slumping; Qcl/Qdo, pl. 3), and in several localities along seacliffs on Cook Inlet southwest of Tutka Bay (glacial till, outwash, and Tertiary sedimentary rocks adjacent to steep seacliffs; unit Qcl Tx, pl. 3). Earthquakes commonly trigger a variety of mass movement.

In addition to the preceding deposits, rocks falling individually from moderate to very steep slopes will accumulate as talus (commonly cone-shaped deposits). Those talus deposits large enough to be mapped at a scale of 1" to 1 mile are shown on plate 3 by the symbol "Qct".

Snow Avalanches

The forms of snow avalanches, and the various conditions of weather and topography which can give rise to avalanches, are numerous. The size may range from small local events to large events involving tens of thousands of tons of snow; velocity of snow movement ranges from slow creep to true avalanches travelling from several miles per hour to as much as three hundred km per hour.

Avalanche prediction is obviously a complex subject, and it is not the purpose of the present study to attempt such prediction for the southern section. Instead, those areas which are known or thought to have experienced snow avalanching are delineated on plate 4. Identification of such areas is based primarily on vegetation "scars" on or adjacent to slopes of moderate to steep gradients. Limitations inherent to this method are as follows: 1) areas may experience avalanches only at highly infrequent intervals, so that no discernible scar exists at present; 2) scars may be due to other processes, such as mud flows or rockfalls (although avalanches often are channelled down pre-existing runoff channels and talus chutes); 3) on steeper slopes or above local treeline, no vegetation exists to precisely delimit areas subject to avalanching. Bare slopes in excess of 45^{o}, for example, are often not prone to massive avalanches because snow will slide off more or less continuously during accumulation.

In view of the aforementioned limitations, plate 4 should be used only as a general guide to areas of snow avalanching. The vulnerability of particular sites to potential avalanches should be assessed on a site-specific basis by qualified personnel; in particular, unusually large avalanches may occur at very infrequent intervals at some sites. Runout zones from such avalanches may extend well beyond the edge of the avalanche zones shown on plate 4.

Tsunamis

The largest recorded tsunami to affect the study area occurred in 1883, had a height (relative to tide level at the time of the tsunami) estimated to have been from 8 to 9 m, and was generated by an eruption of Augustine Volcano. The 1883 tsunami travelled from Augustine Volcano to Port Graham in about 25 minutes; ideally, warning could be given today to coastal communities in time for people to move to high ground in the event of another tsunami-generating eruption.

The probability of even higher tsunamis being generated within Cook Inlet is difficult to assess. Furthermore, given a tsunami of specified magnitude, the prediction of runup heights at specific sites along such an irregular coastline as in the southern section is difficult. For the purposes of this report, it is suggested only that persons carrying out coastal activities keep in mind the fact that a tsunami 8 to 9 m (25 to 30 feet) high had been recorded at Port Graham, that the generating mechanism of that tsunami is still active, and that the tsunami could have arrived at the peak of an extreme high tide.

Unstable Ground

Fissuring, fracturing, and settlement of unconsolidated surficial deposits occurred widely in south-central Alaska during the great earthquake of 1964. Areas especially prone to such failures included thick alluvial deposits in river valleys and on fan-deltas and areas underlain by fine-grained, saturated sediments which may have liquefied during seismic shaking.

No ground failures in 1964 have been reported from the southern section. However, dead trees along the seaward margins of most large alluvial fan-deltas were probably killed by relatively higher seawater levels after the earthquake. The surface gradients of the fan-deltas are low and seawater incursion could be due solely to regional subsidence; local subsidence of fan-deltas by compaction, however, could have occurred there as well.

Extensive deposits of fine-grained saturated sediments were not observed in the study area (except for marine deposits of intertidal flats and deltas), although such deposits may occur beneath the larger floodplains and alluvial fans. Glacial drift is generally thin (unit Qd, pl. 3) but in places exceeds several meters in thickness (unit Qdo, pl. 3); the drift is mainly till but it includes stratified sand and gravel which could be prone to liquefaction.

In general, the areas of potentially most unstable ground in the coastal strip from the Fox River to English Bay are probably the alluvial fan-deltas. Such areas elsewhere during the great earthquake of 1964 were prone to settlement by compaction of sediments, to ground fissuring by liquefaction at depth, and to submarine landsliding. No such ground failures were reported from the present study area, nor was evidence for ground failures found during this study, but failures could occur in future large earthquakes. In addition, proposed development in areas of drift (units Qd, Qdo, pl. 3) and outwash (unit Qo) should be preceded by a detailed site-specific evaluation of the bearing capacity of the surficial deposits, including subsurface (borehole) data.

Floods

Identification of specific areas which would be flooded during 50- and 100-year floods along particular streams requires detailed data on stream discharge and topography. Hydrographic data are available for several streams in the vicinity of Seldovia and for the Bradley River, but the topographic bases are inadequate to define precisely the limits of 50- and 100-year flood areas. Consequently, areas shown on plate 3 as "Qal" are probably the best approximation to areas of potential river flooding available at present. Sand and gravel deposits adjacent to the Greywingk River, Fox River, Sheep Creek, and the river discharging into Neptune Bay are shown on plate 3 as outwash (unit Qo), because these rivers presently head at glaciers. Areas shown on Qo along these rivers should also be included in the list of areas potentially subject to flooding. (The flood of record on the Bradley River for the period 1954-55 and 1957-70 occurred on October 14, 1969; gage height at peak was 9.13 feet (Childers, 1970).)

Glacier surge and outburst flooding have not been identified in the study area (Larry Mayo, pers. comm., 1976). However, a large rockfall in August, 1967 occurred at the nose of Greywingk Glacier; part of the fall entered Graywingk Lake and generated a wave which apparently surged through the outlet of the lake basin. Bedrock was scoured clean of surficial deposits at a channel constriction approximately 2.4 km below the lake outlet (compare 1961 and 1975 aerial photos), to an elevation of about 12 m above the stream level on May 21, 1977. The site of the rockfall was inspected briefly, and several distinct bedrock joints or faults with minor displacement subparallel to the present cliff face were observed. The cliff is approximately 2000 feet above lake level, and the upper (glacially oversteepened) part is nearly vertical in places. A down-dropped block in the steep bedrock wall just down valley from the scar of the 1967 rockfall constitutes a definite hazard from similar rockfalls in the future, and the Greywingk River plain must be considered as potentially subject to flooding by this mechanism.

GLOSSARY OF TERMS

Ash (volcanic) - particles of volcanic ejecta mainly less than 4 mm diameter. Ash often consists of congealed bits of fragmented lava. Fine volcanic ash can remain in the earth's atmosphere for months or years.

Avalanche (snow) - a large mass mainly of snow and ice which moved rapidly down a slope. Avalanches may move at speeds up to 300 km/hour and may be accompanied by destructive wind blasts.

Beach - that part of a shoreline which is regularly exposed and falls under direct wave action. Normally extends from low tide level to the landward side of material which is regularly (though perhaps infrequently) acted upon by the highest waves.

Bedrock - solid, relatively indurated rock. Compare "surficial deposits". The base upon or against which loose deposits rest (for example, alluvial sands and gravels, glacial deposits, beach deposits).

Cretaceous (Period) - a period of geologic time from about 130 million years to 65 million years before present.

Delta (fan-delta) - deposits of river-borne sediments in standing water at the mouth of the river. Fans are cone-shaped river deposits formed at places of abrupt decrease of gradient. As used here, delta refers to that part of a river deposit which comes regularly under the influence of waves.

Drift (glacial) - a term referring to glacial deposits in general. Includes "till" (nonstratified, nonsorted rock material deposited directly by glacial ice) and "stratified drift" (sorted and stratified silts, clays, sands, or gravels deposited in or by glacial meltwater).

Eustatic - refers to world-wide changes in sealevel, as opposed to local changes due to a rise or fall of land.

Fan (alluvial, colluvial) - a broad, cone-shaped deposit formed at a place of abrupt decrease of land surface gradient. Alluvial fans are formed of river-borne sediments; colluvial fans include material moved chiefly by gravity.

Fault - a fracture or break in the earth's crust along which there has been relative movement (displacement). Movement may be abrupt (thereby generating earthquakes) or slow and relatively continuous. Active faults are those along which movement can be expected at any time; the problem in identifying a fault as active is to determine accurately the time of most recent movement.

Fiord - a long deep marine embayment in a valley with high steep sides. Usually refers to a glacially eroded valley with characteristic U-shaped cross-section which has been inundated by the sea.

Floodplain - that part of a river valley which is covered by water when the river floods. Underlain by sediments (usually fine sands and silts) deposited during flood stages of the present river regimen, as opposed to river deposits underlying higher terraces.

Holocene - an epoch of geologic time extending from the end of the Pleistocene to the present, that is, geologic time since about 10,000 years before the present.

Indurated - refers to rocks which have hardened naturally (by heat, pressure, and/or cementation) from an original state of relative looseness.

Intensity - a subjective evaluation of the effects of an earthquake at a particular locality. Depends on many factors, including distance to the earthquake, magnitude, and local geologic conditions. One such intensity scale is the Modified Mercalli Scale.

Intertidal flat - a portion of a shoreline which is regularly exposed during tidal cycles, with an essential flat surface and a surface gradient less than that of any adjacent beach. Commonly underlain by silts or fine sands which are only briefly exposed to wave action during each tidal cycle.

Isostatic - in geology, a term referring to a concept which holds that relatively large portions of the earth's crust act as though they were floating on denser underlying material. Thus, advance of a large glacier will depress the crust due to the added weight of the ice; upon retreat of the ice, the crust will slowly rise.

Jurassic (Period) - a period of geologic time from about 185 million years to about 130 million years before present.

Landslide - movement of rock, surficial deposits, or soil under the influence of gravity. Velocity of movement can range from slow to terminal free-fall velocity. Depending on type of material involved and mechanism of movement, may be classified as a variety of types (debris flows, slumps, translatory slides, rockfalls, etc.).

Liquefaction - a process by which unconsolidated sediments are transformed to a state of little or no shear strength, due to increase of pore water pressures. Commonly occurs during seismic shaking of great magnitude and/or duration, in water-saturated deposits of silt and sand. Effects of liquefaction include fissuring and sand fountaining at the overlying ground surface, and lateral flowage of the liquified deposits and/or overlying deposits.

Littoral drift - movement along a shoreline of materials which comprise beaches, spits, bars, etc. Origin of the movement is in waves and near-shore currents. Direction of movement may vary with storms, tides, seasons, etc., but generally a single direction of movement prevails over a period of years.

Magnitude - the size of an earthquake as relates roughly to the amount of energy released at the source. Magnitudes are determined from seismogram records; "Richter magnitude" is a particular magnitude scale.

Moraine - a constructional deposit of glacial drift (chiefly till), usually with a morphology which is characteristic of the position relative to the ice mass at the time of deposition.

Nuée ardente - French term referring to a hot, highly mobile mixture of gas and fragmented lava which can move rapidly down even slight inclines. A "fiery avalanche"; a type of volcanic eruption which is characteristic of some Aleutian volcanoes.

Outwash - rock material deposited by glacial meltwater streams beyond the glacier ice.

Quaternary (Period) - a period of geologic time beginning about 2 million years before present.

Recurrence interval - the frequency at which earthquakes of a specified magnitude have occurred in a specified area. In using recurrence intervals, the presumption is that the period of recording earthquakes is sufficiently long that the record is a valid predictor of the likelihood of future large earthquakes. Recurrence intervals may not be used to predict the likely time and place of future earthquakes.

Sea stack, sea cave - features indicative of erosion on a rocky coastline. Sea stacks are chimneylike columns of rock isolated from an adjacent headland or cliff, and sea caves are niches or grottos in sea cliffs. Both have their origin in erosion mainly by waves and currents.

Seiche - periodic oscillation of a body of water, generally at least partly enclosed. Seiches may be generated by winds, atmospheric pressure changes, tidal currents, or earthquakes.

Seismic - a term referring to earthquakes or earth vibrations. "Seismicity of a region", for example, generally refers to locations and magnitudes of recorded earthquakes in the region, to analysis of earth stresses and fault movements thought to be responsible for the earthquakes, and to prediction of the likelihood of future large earthquakes in the region.

Spit - a small projection of a shoreline or of a shoal into a body of water. As used here, spit refers to a small, linear or slightly curved projection of beach deposits into the sea.

Submergence - inundation of some land area by the sea, regardless of cause (see "subsidence").

Subsidence - relative fall of some land area, resulting in inundation by the sea if the land area is at the coast.

Surficial (unconsolidated) deposit - relatively loose deposits of transported rock material (river deposits, glacial deposits, etc.), residual soils, or organic deposits at or near the earth's surface (see "bedrock").

Tertiary (Period) - a period of geologic time from about 65 million years to about 2 million years before present.

Till (glacial) - unconsolidated rock materials deposited directly by glaciers. Characterized by poor sorting and absence of marked stratification.

Tombolo - a bar which connects one island to another or to the mainland. As used here, refers to a beach deposit which connects bedrock exposures offshore of the beach to the mainland.

Triassic (Period) - a period of geologic time from about 230 million years to about 185 million years before present.

Tsunami - a seawave generated by some large, short duration disturbance of the ocean floor. Tsunamis may be generated by submarine fault movements (generally by movements involving vertical displacements in shallow water during large earthquakes), by submarine or subaerial landslides (including volcanic eruptions), or by subsidence.

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